CLAIMS

1.- Optical device, apt to generate and process optical codes at at least one wavelength, comprising P inputs s, with $1 \le s \le P$, and $P \ge 1$, and N outputs k, with $1 \le k \le N$ and $N \ge 1$, characterised in that it is apt to simultaneously generate and process N_C phase and/or amplitude optical codes at one or more wavelengths, with $N_C \ge 2$, made of C chips with time interval τ, with $C \ge 2$, characterised in that the transfer function $T_{sk}(f)$ from the input s to the output k satisfies the following formula:

$$|T_{sk}(f)| = \prod_{v=0}^{V-1} \left| F_v\left(a_v f + \frac{S_{sk}}{N_k \tau}\right) \right| \text{, for } s = 1,2..P \qquad k = 1,2,..N$$

where:

- $F_v(f)$ is a transfer function of an optical filter, for $v = 0,1,\ldots,V-1$,
- a_v is a constant value, for $v = 0,1,\ldots,V-1$,
- S_{sk} is an integer number ($S_{sk} \in Z$),
- N_k is a constant value, for $k = 1,2,..N$, and
- V is a positive integer number with $1 \le V \le \log_2 N$.

2. Device according to claim 1, characterised in that the transfer function $T_{sk}(f)$ from the input s to the output k is equal to:

$$T_{sk}(f) = \prod_{v=0}^{V-1} F_v\left(a_v f + \frac{S_{sk}}{N_k \tau}\right) \text{, for } s = 1,2..P \qquad k = 1,2,..N$$

3. Device according to claim 1 or 2, characterised in that the number C of chips of said optical codes is larger than or equal to the number N of outputs k:

$$C \ge N.$$

4 Device according to any one of the preceding claims, characterised in that the number N_C of optical codes which it is apt to simultaneously generate and process is larger than or equal to the number N of outputs k:

$$N_C \ge N.$$

5. Device according to any one of the preceding claims, characterised in that the number N of outputs k is an involution of 2:

$$N = 2^z,$$

with z equal to a positive integer or to 0 (zero).

6. Device according to any one of the preceding claims, characterised in that N_k is an integer constant value, for $k = 1,2,..N$.

7. Device according to any one of the preceding claims, characterised in that the number P of inputs s is equal to 1:

$$P = 1.$$

8. Device according to any one of the preceding claims, characterised in that it comprises at least a tree of optical filters, each filter including an input and two outputs, each tree comprising an input, L levels and N_t outputs, with $L \geq 1$ and $1 \leq N_t \leq 2^L$, each filter having a respective direct transfer function *H(f)* and a respective cross transfer function *G(f)*, the L levels of the tree being located according to an increasing order from the root to the leaves or from the leaves to the root.

9. Device according to claim 8, characterised in that the direct and cross transfer functions *H(f)* and *G(f)* of each optical filter of said at least one tree correspond to the transfer functions of two Finite Impulse Response, or FIR, Quadrature Mirror Filters, or QMFs, of length M, with $M \geq 2$, satisfying the following formula ([12]):

$$G(f) = e^{-j2\pi f\tau} H^*\left(f + \frac{1}{2\tau}\right)$$

where asterisk indicates the complex conjugation.

10. Device according to claim 9, characterised in that the transfer function $T_{sk}(f) = T_k(f)$ from the tree input to an output *k* located on a level V is equal to ([9])

$$\left|T_k(f)\right| = \prod_{\nu=0}^{V-1}\left|F_\nu\left(a_\nu f + \frac{S_{sk}}{N_k \tau}\right)\right| = \prod_{\nu=0}^{V-1}\left|F_\nu\left(2^\nu f\right)\right| \text{, per } k = 1,2,..N_t$$

where:

- each factor $F_\nu(f)$ of the product is equal to $G(f)$ or to $H(f)$, for $\nu = 0,1,\ldots,V-1$,
- $a_\nu = 2^\nu$, for $\nu = 0,1;\ldots,V-1$,
- $S_{sk} = 0$, and
- $V \leq L$.

11. Device according to any one of claims from 8 to 10, characterised in that the coefficients *h[k]* and *g[k]* of the direct and cross transfer functions *H(f)* and *G(f)* of each optical filter satisfy the following

formulas ([1]):

$$g[k] = (-1)^k h[1-k]$$

$$\sum_{k=0}^{M-1} h[k]h[k+2n] = \delta[n] \qquad n \in Z$$

$$\sum_{k=0}^{M-1} h[k] = \sqrt{2}$$

$$\sum_{k=0}^{M-1} (-1)^k h[k] = 0$$

where *δ[n]* is the Kronecker delta function.

12. Device according to any one of claims from 8 to 11, characterised in that each optical filter is a planar filter with unit delay $2^l \tau$, where l is the level on which the filter is located, with $0 \le l \le L-1$, the L levels of the tree being identified by the index l according to an increasing order from the root to the leaves or from the leaves to the root.

13. Device according to claim 8 or 9, characterised in that the transfer function $T_{sk}(f) = T_k(f)$ from the input to an output k satisfies the following formula ([11])

$$|T_k(f)| = \prod_{v=0}^{V-1} \left| F_v\left(a_v f + \frac{S_{sk}}{N_k \tau}\right) \right| = \left| F_0\left(f + \frac{S_k}{N_t \tau}\right) \right| \text{, for } k = 1,2,..N_t$$

where:

- $F_0(f)$ is a reference transfer function,
- $a_v = 1$,
- $S_{sk} = S_k$,
- $N_k = N_t$, and
- $V = 1$.

14. Device according to claim 8 or 9, characterised in that the transfer function $T_{sk}(f) = T_k(f)$ from the input to an output k satisfies the following formula ([11])

$$|T_k(f)| = \prod_{v=0}^{V-1} \left| F_v\left(a_v f + \frac{S_{sk}}{N_k \tau}\right) \right| = \left| F_0\left(f + \frac{S_k}{2^l \tau}\right) \right| \text{, for } k = 1,2,..N_t$$

where:

- $F_0(f)$ is a reference transfer function,
- $a_v = 1$,
- $S_{sk} = S_k$,
- $N_k = 2^l$,
- l is the level on which the output k is located, with $0 \le l \le L-1$, the L tree levels being identified by the index l according to an increasing order from the root to the leaves or from the leaves to the root, and
- $V = 1$.

15. Device according to any one of claims from 8 to 14, characterised in that each optical filter comprises at least one Mach-Zehnder Interferometer or MZI.

16. Device according to claim 15, characterised in that each optical filter has input and output 3dB symmetrical directional couplers.

17. Device according to claim 15 or 16, characterised in that each optical filter comprises only one MZI, having length $M = 2$ and delay between arms $2^l\tau$, where l is the level on which the filter is located, with $0 \le l \le L-1$, the L tree levels being identified by the index l according to an increasing order from the root to the leaves or from the leaves to the root.

18. Device according to claim 15 o 16, characterised in that each optical filter comprises a chain of two MZIs, said chain having length $M = 4$ and delay between arms $2^l\tau$ and $2^{l+1}\tau$, where l is the level on which the filter is located, with $0 \le l \le L-1$, the L tree levels being identified by the index l according to an increasing order from the root to the leaves or from the leaves to the root.

19. Device according to any one of claims from 15 to 18, characterised in that a $\Delta\Phi$ constant phase optical phase shifter is inserted along at least one of the arms of at least one MZI.

20. Device according to any one of claims from 1 to 7, characterised in that it comprises at least one tree having at least one node comprising a first coupler (21), including N_{IN} input waveguides and N_a output waveguides, with $N_{IN} \ge 1$ and $N_a \ge 1$, the outputs of which are connected to a grating (22) including N_a waveguides, which are in turn connected to N_a input waveguides of a second coupler (23), including N_{OUT} output waveguides, where $N_{OUT} \ge 1$.

21. Device according to claim 20, characterised in that $N_{IN} = N_a =$

$N_{OUT} = N_{GRA}$.

22. Device according to claim 20 or 21, characterised in that a constant optical phase shifter of value θ_j is inserted along at least one of the waveguides j of the grating (22) with $j = 1,2,\ldots N_a$.

23. Device according to any one of claims from 20 to 22, characterised in that the lengths L_j, with $j=1,2\ldots N_a$, of the waveguides of the grating (22), with $j=1,2\ldots N_a$, are equal to ([18])

$$L_j = L_{m'} + d_j \Delta L \qquad j = 1,2,\ldots N_a$$

with the integer number $d_j \in [0,1,2,\ldots N_a - 1]$ satisfying the condition $d_k \neq d_{k'}$ if $k \neq k'$, where $L_{m'}$ is the length of a reference waveguide, equal to the shortest waveguide, whereby $d_{m'} = 0$, and ΔL is the minimum difference between the lengths of two waveguides of the grating (22).

24. Device according to claim 23, characterised in that ([33])

$$d_j = \left\{ \frac{1}{2}\left[(-1)^{j+m'}\left(j - \frac{1}{2}\right) - \left(m' - \frac{1}{2}\right)\right]\right\} \bmod N_a \quad . \quad m', j = 1,2,\ldots N_a$$

where "*mod*" indicates the arithmetical module operator.

25. Device according to claim 23, characterised in that $d_j = 2j$, with $j = 1,2\ldots,N_a$, where only the even inputs i ($i = 2r$, for $r = 1,2,\ldots,int[N_{IN}/2]$, where "*int*" indicates the arithmetical operator giving the integer quotient of a division) and the even outputs k ($k = 2r'$, for $r' = 1,2,\ldots,int[N_{OUT}/2]$) are used.

26. Device according to any one of claims from 20 to 25, characterised in that the first coupler is a uniform Multi Mode Interference or MMI coupler (21).

27. Device according to any one of claims from 20 to 25, characterised in that the first coupler is a non uniform power splitter MMI coupler (21).

28. Device according to claim 26 or 27, characterised in that the first MMI coupler (21) has a length

$$L_c = M_c 3 L_\pi / N_a,$$

where M_c is a positive integer number, and([13])

$$L_\pi = \frac{\pi}{\beta_0 - \beta_1} = \frac{4n_g W_e^2}{3\lambda}$$

where

- β_0 and β_1 are propagation constants of the zeroth and first order modes, respectively,
- n_g is the effective refractive index,
- λ is the free space wavelength of the input radiation, and
- W_e is the effective width of the fundamental transverse mode,

the device being further characterised in that, assuming that the first MMI coupler input waveguides are identified by an index i which increases according to a transverse direction and that the output waveguides are identified by an index j' which increases according to said same transverse direction, the input waveguides i and the output waveguides j' are located, respectively, in positions x_i and $x_{j'}$ equal to ([14]):

$$x_i = (2i-1)\frac{W_e}{2N_{IN}} \qquad i = 1,2,\ldots N_{IN}$$

$$x_{j'} = (2j'-1)\frac{W_e}{2N_a} \qquad j' = 1,2\ldots N_a$$

29. Device according to claim 28, characterised in that M_c and N_a are two positive integer numbers without a common divisor larger than 1.

30. Device according to claim 28 or 29, characterised in that $M_c = 1$.

31. Device according to any one of claims from 20 to 30, characterised in that the second coupler is a uniform MMI coupler (23).

32. Device according to any one of claims from 20 to 30, characterised in that the second coupler is a non uniform power splitter MMI coupler (23).

33. Device according to claim 31 or 32, characterised in that the second MMI coupler (23) has a length

$$L'_c = M'_c 3L'_\pi / N_{OUT},$$

where M'_c is a positive integer number and ([13])

$$L'_\pi = \frac{\pi}{\beta'_0 - \beta'_1} = \frac{4n'_g W'^2_e}{3\lambda}$$

where

- β'_0 and β'_1 are propagation constants of the zeroth and first order

modes, respectively,

- n'_g is the effective refractive index,
- λ is the free space wavelength of the input radiation, and
- W'$_e$ is the effective width of the fundamental transverse mode,

the device being further characterised in that, assuming that the second MMI coupler input waveguides are identified by an index j'' which increases according to a transverse direction and that the output waveguides are identified by an index k which increases according to said same transverse direction, the input waveguides j'' and the output waveguides k are located, respectively, in positions $x'_{j''}$ and x'_k equal to ([14]):

$$x'_{j''} = (2j''-1)\frac{W_e'}{2N_a} \qquad \text{for } j''=1,2,\ldots,N_a$$

$$x'_k = (2k-1)\frac{W_e'}{2N_{OUT}} \qquad \text{for } k=1,2,\ldots,N_{OUT}$$

34. Device according to claim 33, characterised in that M'_c and N_{OUT} are two positive integer numbers without a common divisor larger than 1.

35. Device according to claim 33 or 34, characterised in that $M'_c = 1$.

36. Device according to any one of claims from 33 to 35, when depending on each one of claims 21, 22 and 28, characterised in that the values θ_j of the phase shifters along the waveguides of the grating (22) are equal to ([20])

$$\varphi_{ij} + \varphi'_{jm} + \theta_j = 2\pi A_{ikm}$$

for $i=1,2,\ldots,N_{IN}$ $\quad j=1,2,\ldots,N_a$ $\quad m=1,2,\ldots,N_{OUT}$ $\quad k=1,2,\ldots,N_{OUT}$

where ([15])

$$\varphi_{ij} = \phi_1 - \frac{\pi}{2}(-1)^{i+j+N_{GRA}} + \frac{\pi}{4N_{GRA}}\left[i+j-i^2-j^2+(-1)^{i+j+N_{GRA}}\left(2ij-i-j+\frac{1}{2}\right)\right]$$

with ([16])

$$\phi_1 = -\beta_0\frac{3M_cL_\pi}{N_{GRA}} - \frac{9\pi}{8N_{GRA}} + \frac{3\pi}{4},$$

and ([20])

$$\varphi'_{jm} = \phi'_1 - \frac{\pi}{2}(-1)^{j+m+N_{GRA}} + \frac{\pi}{4N_{GRA}}\left[j + m - j^2 - m^2 + (-1)^{j+m+N_{GRA}}\left(2jm - j - m + \frac{1}{2}\right)\right]$$

with ([16])

$$\phi'_1 = -\beta'_0 \frac{3M'_C \dot{L}'_\pi}{N_{GRA}} - \frac{9\pi}{8N_{GRA}} + \frac{3\pi}{4} \quad ,$$

where

A_{ikm} are integer constants.

37. Device according to any one of claims from 20 to 36, characterised in that the absolute value of the transfer function $T_{ik}(f)$ from an input i of the first coupler to the output k of the second coupler is a frequency translated copy of the absolute value of the reference transfer function $T_{im}(f)$, from the input i of the first coupler (21) to an output m of the second coupler (23), so that ([24]):

$$|T_{ik}(f)| = \prod_{v=0}^{V-1}\left|F_v\left(a_v f + \frac{S_{ik}}{N_k \tau}\right)\right| = \left|T_{im}\left(f - n\frac{c}{n_e N_k \Delta L}\right)\right|$$

for $i = 1,2,\ldots,N_{IN} \qquad k,m = 1,2,\ldots,N_{OUT}$

where:

- $F_0(f) = T_{im}(f)$,
- c is the light speed,
- $a_v = 1$,
- n_e is the refractive index of the waveguides of the grating (22),
- $V = 1$, and
- $S_{sk} = -n$, where n is an integer number satisfying the condition that the values corresponding to two different outputs k e k' are different ([25]):

$$k \neq k' \rightarrow n \neq n' \qquad k,k' = 1,2,\ldots,N_{OUT}$$

whereby the time constant τ is equal to:

$$\tau = \frac{\Delta L \cdot n_e}{c} \ .$$

38. Device according to claim 37, characterised in that $N_k = N_{OUT}$ for $k=1,2,\ldots,N_{OUT}$.

39. Device according to any one of claims from 20 to 25,

characterised in that the first coupler is a focusing coupler or "slab".

40. Device according to any one of claims from 20 to 25, characterised in that the second coupler is a focusing coupler or "slab".

41. Device according to each of claims 39 and 40, characterised in that the location of the input and output waveguides on the first coupler and on the second coupler is based on the Rowland circle construction.

42. Device according to any one of claims from 39 and 41, characterised in that the length of the adjacent waveguides in the grating varies by a constant ΔL.

43. Device according to any one of claims from 39 to 42, characterised in that ([40]):

$$N_a = \frac{\lambda R}{n_s d d_o}$$

where:

- λ is the wavelength of the input optical signal,
- R is the focal length of the first and second focusing couplers,
- n_s is the effective refractive index of the first and second focusing couplers,
- d is the pitch of the waveguide grating, and
- d_o is the pitch of the N_{IN} input waveguides and the N_{OUT} output waveguides.

44. Device according to any one of claims from 39 to 43, characterised in that, assuming that the N_{IN} input waveguides and the N_{OUT} output waveguides are identified, respectively, by an index i and by an index k which increase according to the same transverse direction, the absolute value of the transfer function $T_{ik}(f)$ from an input i of the first coupler to the output k of the second coupler is a frequency translated copy of the absolute value of a reference transfer function $T_{im_{REF\_i}}(f)$, from the same input i to a corresponding reference output m_{REF_i}, with $1 \le m_{REF\_i} \le N_{OUT}$, so that ([44]):

$$\left|T_{ik}(f)\right| = \prod_{v=0}^{V-1}\left|F_v\left(a_v f + \frac{S_{ik}}{N_k \tau}\right)\right| = \left|T_{im_{REF\_i}}\left(f - \frac{i+k}{N_k \tau}\right)\right| \quad i = 1,2,\ldots,N_{IN} \quad k = 1,2,\ldots,N_{OUT}$$

where:

- $F_0(f) = T_{im_{REF\_i}}(f)$,
- c is the light speed,
- $a_v = 1$,
- n_e is the refractive index of the waveguides of the grating (22),
- $V = 1$,
- $S_{sk} = (i + k)$, and
- the time constant τ is equal to:

$$\tau = \frac{\Delta L \cdot n_e}{c} .$$

45. Device according to claim 44, when depending on claim 21, characterised in that the index m_{REF_i} of the reference output waveguide corresponding to the input i is equal to:

$$m_{REF\_i} = \begin{cases} N_{GRA} - i & \text{for } \ i \neq N_{GRA} \\ N_{GRA} & \text{for } \ i = N_{GRA} \end{cases} \qquad i = 1,2,\dots,N_{GRA}$$

46. Device according to claim 44 or 45, characterised in that $N_k = N_{OUT}$ for $k=1,2,\dots,N_{OUT}$.

47. Optical signal comprising at least one phase and/or amplitude optical code including C chips of interval τ at at least one wavelength, characterised in that it is generated at at least one of the N outputs k of the optical device according to any one of the preceding claims from 1 to 46, by sending at least one optical signal to at least one of the P inputs s of the optical device.

48. Optical signal according to claim 47, characterised in that the chip phases of said at least one code are integer multiples of $2\pi/C$, i.e. they are equal to $2k_2\pi/C$ with k_2 positive or negative integer or null ($k_2 \in Z$).

49.- Optical signal according to claim 47 or 48, characterised in that said at least one optical code is a PSK code.

50.- Optical signal according to any one of claims from 47 to 49, characterised in that said at least one optical code is generated by the optical device according to any one of the preceding claims from 20 to 46, by sending U impulse optical signals, with $2 \leq U \leq P$, to U corresponding inputs s of the optical device.

51.- Optical signal according to claim 50, characterised in that $U = \text{int}\,(P/2)$.

52.- Optical signal according to claim 50 or 51, characterised in that said U impulse optical signals have the same wavelength.

53.- Optical signal comprising at least one phase and/or amplitude optical code including C chips of interval τ at at least one wavelength, with $C \geq 2$, characterised in that the chip phases of said at least one code are integer multiples of $2\pi/C$, i.e. they are equal to $2k_2\pi/C$ with k_2 positive or negative integer or null ($k_2 \in Z$).

54.- Optical signal according to claim 53, characterised in that said at least one code includes said C chips at at least two wavelengths.

55.- Communication network, comprising one or more code generating devices (1), and one or more code processing and recognising devices (4, 5), characterised in that at least one of said one or more code generating devices (1) and/or at least one of said one or more code processing and recognising devices (4, 5) comprises at least one optical device (6) according to any one of the preceding claims from 1 to 46.

56.- Communication network according to claim 55, characterised in that said at least one optical device (6) is included within at least one of said one or more code generating devices (1) for associating at least one optical code (2) to one or more information optical signals (3).

57.- Communication network according to claim 55 or 56, characterised in that said at least one optical device (6) is included within at least one of said one or more code processing and recognising devices (4, 5) for controlling at least one optical switcher (13) on the basis of at least one recognised optical code (2).

58.- Communication network according to claim 57, characterised in that said at least one of said one or more code processing and recognising devices (4, 5) within which said at least one optical device (6) is included is a router device.

59.- Communication network according to any one of claims from 55 to 58, characterised in that it is a Multi Protocol Label Switching or MPLS communication network.

60. Communication network according to any one of claims from 55 to 58, characterised in that it is a Code Division Multiple Access or CDMA communication network.

61. Code generating device (1), characterised in that it comprises an optical device (6) according to any one of the preceding claims from 1 to 46, and in that it is apt to be used in a communication network according

to any one of claims from 55 to 60.

62. Code processing and recognising device (4, 5), characterised in that it comprises an optical device (6) according to any one of the preceding claims from 1 to 46, for controlling at least one optical switcher (13) on the basis of at least one recognised optical code (2), and in that it is apt to be used in a communication network according to any one of claims from 55 to 60.

63. Code processing and recognising device (4, 5) according to claim 62, characterised in that it is a router device.